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Chapter 5 Bromide

Overview

This chapter discusses bromide data collected at 14 Municipal Water Quality Investigations Program (MWQI) monitoring stations during the reporting period. Bromide concentrations varied widely among stations depending on the geographic location and hydrologic conditions (Table 5-1). The stations could be grouped into low, medium, and high categories according to their median bromide concentrations.

Table 5-1 Summary of bromide at 14 MWQI stations

The stations having low bromide concentrations included 3 river stations—American River at E.A. Fairbairn Water Treatment Plant (WTP), Sacramento River at the West Sacramento WTP Intake, and Sacramento River at Hood. Also in this category was an urban drainage station, the Natomas East Main Drainage Canal (NEMDC). Bromide at the Sacramento River stations ranged from <0.01 mg/L to 0.03 mg/L (Table 5-1). Bromide was always below the reporting limit at the American River station. At NEMDC, bromide ranged between 0.01 and 0.10 mg/L with a median concentration of 0.06 mg/L.

Stations with medium bromide concentrations included 2 channel stations—Old River at Station 9 and Old River at Bacon Island—and 3 diversion stations—Banks Pumping Plant, Delta-Mendota Canal (DMC), and the Contra Costa Pumping Plant. Bromide levels at these stations were variable, but median concentrations of bromide ranged from 0.09 to 0.15 mg/L (Table 5-1).

Stations with high bromide concentrations included the Sacramento River at Mallard Island, San Joaquin River (SJR) near Vernalis, SJR at Highway 4, and 2 agricultural drainage stations—Bacon Island Pumping Plant and Twitchell Island Pumping Plant.

Bromide was detected in all 34 monthly samples collected from the Mallard Island station, which is close to the San Francisco and Suisun bays. Concentrations ranged from 0.03 to 20.00 mg/L at this station, which is the most widely variable among all 14 MWQI stations (Table 5-1). The median concentration was 1.90 mg/L. High bromide levels at this station were attributable to seawater influence because bromide in Delta rivers, channels, and agricultural drains was much lower than what was observed at this station.

Bromide concentrations at SJR near Vernalis and at Highway 4 were similar despite differences in sampling frequency (Table 5-1). Bromide concentrations at the 2 agricultural drainage stations were high with concentrations higher at Twitchell Island station than at the Bacon Island station.

Seasonal Variations and Differences among Stations

American River WTP and Sacramento River Stations

Bromide was not detected at the American River at E.A. Fairbairn WTP station. At the Sacramento River stations at West Sacramento WTP Intake and Hood, bromide concentrations ranged from <0.01 mg/L to 0.03 mg/L (Table 5-1). Although the West Sacramento WTP Intake station was sampled monthly and the Hood station was sampled weekly, the percentage of positive detects at the 2 stations were 71% and 75%, respectively. The ranges, data dispersion, and average concentrations were the same for both stations. Medians were also similar (0.01 and 0.02 for Hood and West Sacramento WTP Intake, respectively).

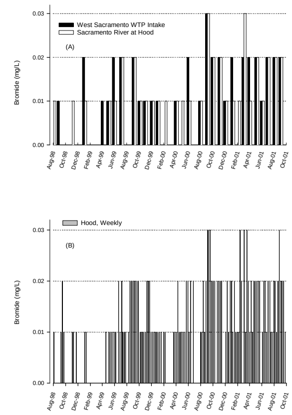


Figure 5-1 Bromide at two Sacramento River stations

Temporal patterns of bromide at both the West Sacramento WTP Intake and Hood stations were similar (Figure 5-1). Bromide concentrations were higher during the 2001 water year of low runoff than during the 1999 and 2000 water years of higher runoff. More positive samples were found during the 2001 water year than during either of the previous 2 water years (Figure 5-1). At both stations, bromide concentrations were generally higher during the dry months than during the wet months. During February and March of each year, bromide was either not detected or was lower than bromide concentrations in the dry months. Temporal patterns were similar, and the average bromide concentrations at both stations were statistically the same ($p=0.708$).

San Joaquin River Stations

The SJR near Vernalis was monitored weekly, and the SJR at Highway 4 was monitored monthly. Bromide concentrations at either site were seldom below the reporting limit (Table 5-1). Despite differences in sampling frequency, both average and median bromide concentrations at these stations were the same (Table 5-1). The ranges and data dispersion were also similar.

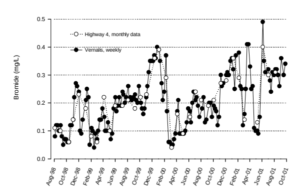


Figure 5-2 Bromide at two San Joaquin River stations

Seasonal pattern of bromide differed from that of organic carbon at these stations. Organic carbon could be high during wet months depending on rainfall events in the watershed, but generally lower and less variable during the dry months (Chapter 4). Bromide concentrations also were generally high during the wet months (Figure 5-2); however, bromide could also be high during the dry months. Bromide generally increased starting in May of each year. Bromide began to level off or decline during August or September and usually reached a low point in October. During the wet months, bromide reached its highest concentration from November through February and was lowest during the month of March. In general, bromide levels appear to be inversely related to the amount of annual precipitation during the reporting period (Figure 5-2).

Seasonal patterns of bromide in the SJR reflect the effects of both rainfall and agricultural practices in the watershed. The San Joaquin Valley is mostly irrigated agricultural land. Irrigation water for the area comes from the DMC, a Delta diversion station, and contains considerable bromide (Table 5-1); and it recirculates within the San Joaquin Valley. When irrigation water is applied, bromide concentrates on the soil surface through evapotranspiration. Following either irrigation or rainfall, runoff water carries previously accumulated bromide on the soil surface and moves into the SJR. Soils in some areas were developed from old marine deposits that contain high levels of bromide, which may be concentrated on the soil surface and washed into the river during wet months of low to moderate rainfall. In some areas, shallow groundwater also carries high levels of bromide and moves into the SJR through seepage. On the other hand, inflow water in the upstream watershed with low bromide is mostly trapped in upstream reservoirs for flood control or storage purposes during the wet months resulting in less dilution downstream; therefore, bromide concentrations in the lower part of the river are high during the wet months.

During the dry months, irrigation return waters containing high levels of bromide are discharged into the SJR. Thus, bromide concentrations generally increased during periods of peak irrigation (May through September) and decreased at the end of the irrigation season prior to increases in the wet months (Figure 5-2).

During the reporting period, the 1999 and 2000 water years were above-normal runoff years, whereas the 2001 water year was a dry year in the SJR watershed (refer to Chapter 3). The overall bromide concentrations in the 2001 water year were the highest among the 3 water years, especially during the dry months. This was attributable to irrigation returns with modest bromide concentrations and decreased inflows with low bromide levels from the tributaries on the east side of the upper SJR.

Bromide concentrations were not statistically different (p=0.71) at SJR near Vernalis and SJR at Highway 4 despite urban influence at the latter site. This suggests that urban contribution may not be a major source of bromide to the river.

Channel Stations

MWQI monitored bromide at 2 channel stations—Old River at Station 9 and Old River at Bacon Island. Bromide was always above the reporting limit (Table 5-1). Median concentrations of bromide were 0.09 mg/L at Bacon Island and 0.12 mg/L at Station 9. This difference was probably the result of Sacramento River water influence at these sites.

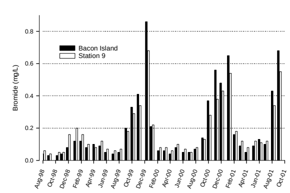


Figure 5-3 Monthly bromide concentrations at two Old River stations

Temporal changes of bromide at both stations were similar to those of organic carbon in that concentrations were higher during the wet months and remained lower and relatively unchanged during the dry months (Figure 5-3). This differed from the seasonality patterns of the 2 SJR stations. Despite increased bromide concentrations during the wet months, there was little change in bromide concentrations at either station during the dry months. Average bromide was the highest in the 2001 water year (the dry year) despite a higher bromide level in December of 1999. Statistical analysis showed no significant difference in average bromide concentrations between the 2 channel stations (p=0.343). The average and median bromide levels are presented in Table 5-1.

Diversion Stations

At the Delta diversion stations—Banks Pumping Plant, DMC, and Contra Costa Pumping Plant—median bromide levels varied from 0.11 to 0.15 mg/L. Average bromide concentrations ranged from 0.17 to 0.22 mg/L (Table 5-1). The seasonal patterns were similar for all 3 stations (Figure 5-4). In general, bromide reached its highest value from October through March of each water year. Bromide concentrations were lower from April through August (Figure 5-4). These seasonal patterns were different from those observed at the SJR stations reflecting the influences of multiple sources at the diversion pumps.

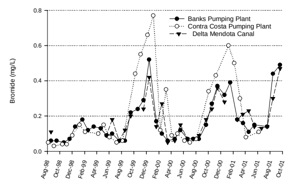


Figure 5-4 Bromide at three diversion stations

Due to differences in sampling frequency, statistical comparisons of the stations' average bromide concentrations were not possible. However, a Wilcoxon Rank-sum test of bromide levels at Banks and DMC, which were sampled on the same day, found no significant differences between average bromide levels at the 2 stations ($p=0.40$). During most of the wet months of the 2000 and 2001 water years, bromide was higher at the Contra Costa Pumping Plant than at the other 2 diversion stations (Figure 5-4); little difference was noticed during the 1999 water year.

Higher bromide at the Contra Costa Pumping Plant is perhaps due to the station's proximity to the Mallard Island station and the likely seawater influence (Figure 1-1). Seawater influence is related to Delta outflows. The 1999 water year was an above-normal year, but the 1998 water year was a wet year. Delta outflows in 1999 were the highest among the 3 water years due to carry-over water from the 1998 water year (refer to Chapter 3). Although the 2000 water year was also an above-normal year, the 1998 carry-over effect had disappeared; therefore, outflow in the 2000 water year was lower than in the 1999 water year. Delta flow was lowest in the 2001 water year, a dry year (refer to Chapter 3). Reduced outflows resulted in greater seawater influence to the western part of the Delta during the 2000 and 2001 water years. During the wet months of these water years, bromide concentrations were higher at Contra Costa Pumping Plant than at the other 2 diversion stations.

Sources of Bromide in Delta Waters

Seawater Influence

Seawater influence can occur when Delta outflows are not sufficiently strong to prevent seawater from entering the western Delta. Seawater influence often occurs during dry runoff years or during the dry months when Delta inflows from the watershed are low and while pumping at the diversion stations are high. In addition, seawater influence occurs when upper reservoirs and lakes are closed for water storage purposes or for flood control during the wet months of a water year. Seawater influences and normal tidal mixing increase bromide concentrations at the stations throughout the western Delta.

The Mallard Island station is indicative of seawater influence among the stations. Water at this station is a mixture of water from various rivers and channels in the Delta as well as water from the Bay. A total of 34 monthly samples were collected from this station during the reporting period. Bromide was always above the reporting limit (Table 5-1). Concentrations ranged from 0.03 to 20.00 mg/L, making it the most widely variable of all 14 stations (Table 5-1). The average bromide level was 4.45 mg/L. The median concentration was 1.90 mg/L. Because rivers, channels, and agricultural drains of the Delta all had substantially lower bromide levels, the high bromide at Mallard Island was attributable to seawater influence.

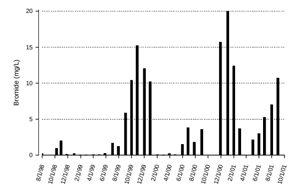


Figure 5-5 Bromide concentrations at the Mallard Island station

Bromide at the Mallard Island station was much higher during the dry water year than during the above-normal or wet years (Figure 5-5). In the 1999 water year, runoff was the highest and bromide was the lowest among the 3 water years. Of the 2000 and 2001 water years, bromide was higher in both the wet and dry months of the 2001 water year—a dry year. The 2000 water year was an above-normal year (Figure 5-5). Increases in bromide at Mallard during the 2001 water year appear to have been directly related to runoff in the contributing watersheds. As shown in Figure 3-3, Delta outflows were the highest in the 1998 water year, and the lowest during the 2001 water year. A wet year in 1998 and residual outflows from the 2 previous years, which also were wet years, contributed to the higher flows in 1998 (Table 3-3). When outflows decrease, seawater influence and thus bromide concentrations increase.

Recirculation of Bromide within the San Joaquin Valley

The SJR contributes significant amounts of bromide to the Delta. Both average and median bromide concentrations of the river were 0.20 mg/L (Table 5-1). Bromide levels increased during the wet months of each water year. Bromide concentrations were higher during the dry year than during the previous 2 wetter years (Figure 5-2). Bromide from seawater enters the San Joaquin Valley as irrigation water taken from the Delta (discussed in section "San Joaquin River Stations"). Bromide in the irrigation water is concentrated in the agricultural lands and returned to the Delta through the SJR. Most of the bromide in the San Joaquin Valley can be accounted for this way, but the valley also has intrinsic bromide sources, such as bromide from shallow groundwater or from soils developed from old marine deposits.

The hydrology of the Delta is complex, and the accurate percentage of SJR water at specific pumping stations at specific time periods remains unknown. A significant proportion of bromide in south Delta waters may come from the SJR.

Bromide from Delta Islands

Delta soils are peaty soils formed when the area was a tidal wetland. Bromide and salts also accumulate in Delta island soils through irrigation. Some islands have shallow groundwater, which also contributes bromide through seepage. When agricultural drainage water is pumped back into the Delta, bromide is released into Delta channels. Median bromide in agricultural drainage return waters ranged from 0.18 to 0.34 mg/L during the reporting period (Table 5-1). Bromide concentrations in drainage waters at both Bacon and Twitchell islands fluctuated but remained high throughout each water year except June through August when bromide was lower (Figure 5-6). Lower concentrations between June and August may be due to

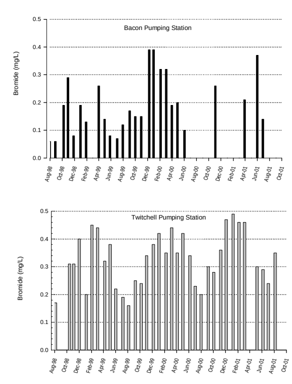


Figure 5-6 Bromide at two Delta agricultural pumping stations

high demand of crop water. Heavy and frequent watering causes irrigation water overflows, which probably dilute bromide concentrations in drainages. In contrast, bromide increased during the wet months because farmers apply water to the land specifically to leach salts including bromide, which returns to the channels during the winter. Heavy rainfall during the wet months also causes surface runoff carrying bromide accumulated during the summer to the ditches, thus bromide is higher during the wet months.

Bromide is higher at Twitchell Island than at Bacon Island. Twitchell Island is geographically closer to the seawater-affected waters of San Francisco and Suisun bays (refer to Figure 1-1), thus salinity in water of the channels near Twitchell Island is generally higher. Irrigation water for Twitchell Island primarily comes from the SJR, which contains high concentrations of bromide. In contrast, Bacon Island is irrigated with water from the Old River, which is mostly water from the Sacramento River and generally low in bromide.

Urban Drainage

Urban drainage was not a major source of bromide in Delta waters. Figure 5-7 presents available data during the reporting period at NEMDC. Bromide ranged between 0.01 and 0.10 mg/L. The majority of the data were from 0.02 to 0.09 mg/L with a median concentration of 0.06 mg/L (Table 5-1). No apparent seasonal or temporal trend was found (Figure 5-7). A comparison of bromide concentrations in the SJR near Vernalis and at Highway 4 also concluded that urban drainage was not a significant source of bromide to the SJR (see section “San Joaquin River Stations”).

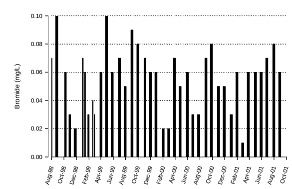


Figure 5-7 Bromide at the Natomas East Main Drainage Canal

The Relationship between Bromide and Chloride in Delta Waters

As discussed in previous sections, bromide in the Delta originates from seawater either directly or indirectly. Seawater contains approximately 65 mg/L of bromide and 19,000 mg/L of chloride; the bromide/chloride ratio in seawater is roughly 0.0034. Like chloride, bromide is conservative. This ratio should hold in Delta waters if seawater is the sole source of bromide and chloride.

Among the stations monitored, 4 stations are unaffected by seawater. These include (1) American River at E.A. Fairbairn WTP, (2) Sacramento River at West Sacramento WTP Intake, (3) Sacramento River at Hood, and (4) NEMDC. At the 2 Sacramento River stations, a total of 145 samples had both bromide and chloride at or above their respective reporting limits (Figure 5-8(a)). The relationship between bromide and chloride at these 2 stations was weak (r^2=0.333), probably due to the mostly low bromide levels near the reporting limit. At NEMDC both bromide and chloride were detected at or above their reporting limits in all 41 monthly samples, but the relationship between bromide and chloride also was weak (Figure 5-8(b), r^2=0.284). The majority of data suggests that bromide did not increase with the increase of chloride. The NEMDC collects urban drainage from the Roseville area and much of the Sacramento area north of the American River. High chloride concentrations were probably attributable to use of chlorine products in urban areas. Because bromide is seldom used in urban

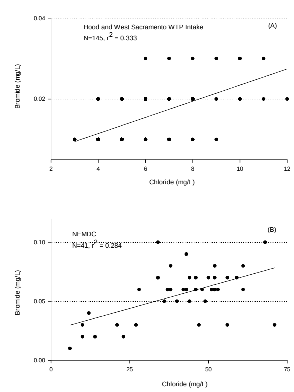


Figure 5-8 Bromide and chloride relationship at three stations

areas, a linear relationship between bromide and chloride should not be expected at NEMDC. Due to lack of either positive detects or a reliable linear relationship, data from these 4 stations were not included in the analysis of the relationship between bromide and chloride in seawater-influenced stations.

A total of 427 samples were collected from the remaining 10 stations, 2 of which were agricultural drainage stations. A strong linear relationship existed between bromide and chloride (Figure 5-9). This relationship may be described by this linear regression equation:

$$\text{bromide} = 0.0035 * \text{chloride} - 0.019, \; [\, r^2 = 0.996, \; p<0.0001]$$

Thus, the bromide/chloride ratio in Delta waters is 0.0035, which is close to the ratio found in seawater. This analysis confirms that the source of bromide in the Delta is seawater. The above equation suggests that bromide concentrations at the 10 seawater-influenced stations may be estimated by multiplying the concentration of chloride with an empirical constant of 0.0035, as the regression intercept is negligible.

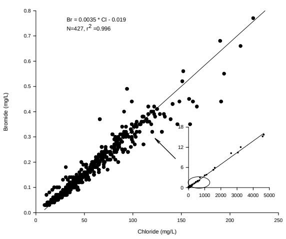


Figure 5-9 The relationship between bromide and chloride at 10 stations

Table 5-1 Summary of bromide at 14 MWQI stations (mg/L)

Station	Positive detects/ Sample number[a]	Range	Majority data range	Data dispersion (IQR)	Average	Median
American and Sacramento River stations						
American River at E.A. Fairbairn WTP	0/37	<0.01				
West Sacramento WTP Intake	27/38	0.01–0.03	0.01–0.02	0.01–0.02	0.02	0.02
Sacramento River at Hood	118/158	0.01–0.03	0.01–0.03	0.01–0.02	0.02	0.01
Sacramento River at Mallard Island	34/34	0.03–20.00	0.03–15.38	0.21–6.72	4.45	1.90
San Joaquin River stations						
San Joaquin River near Vernalis	157/159	0.04–0.49	0.06–0.37	0.12–0.26	0.20	0.20
San Joaquin River at Highway 4	36/37	0.04–0.40	0.06–0.37	0.14–0.27	0.20	0.20
Delta channel stations						
Old River at Station 9	38/38	0.04–0.68	0.05–0.54	0.07–0.22	0.18	0.12
Old River at Bacon Island	38/38	0.03–0.86	0.04–0.65	0.05–0.21	0.19	0.09
Diversion stations						
Banks Pumping Plant	37/37	0.05–0.52	0.06–0.45	0.07–0.21	0.17	0.14
Delta-Mendota Canal (DMC)	29/29	0.05–0.47	0.06–0.40	0.11–0.24	0.18	0.15
Contra Costa Pumping Plant	30/30	0.03–0.77	0.04–0.63	0.07–0.35	0.22	0.11
Agricultural drainage stations						
Bacon Island Pumping Plant	26/26	0.06–0.39	0.06–0.39	0.12–0.26	0.19	0.18
Twitchell Island Pumping Plant	35/36	0.16–0.49	0.19–0.46	0.25–0.41	0.33	0.34
Urban drainage station						
Natomas East Main Drainage Canal (NEMDC)	41/41	0.01–0.10	0.02–0.09	0.04–0.07	0.06	0.06

Note: All statistics are calculated for positively detected samples; positive detects are samples with concentration greater than the reporting limit of 0.01 mg/L.
a. Positive detects are samples with concentration greater than the reporting limit of 0.01 mg/L.

Figure 5-1 Bromide at two Sacramento River stations

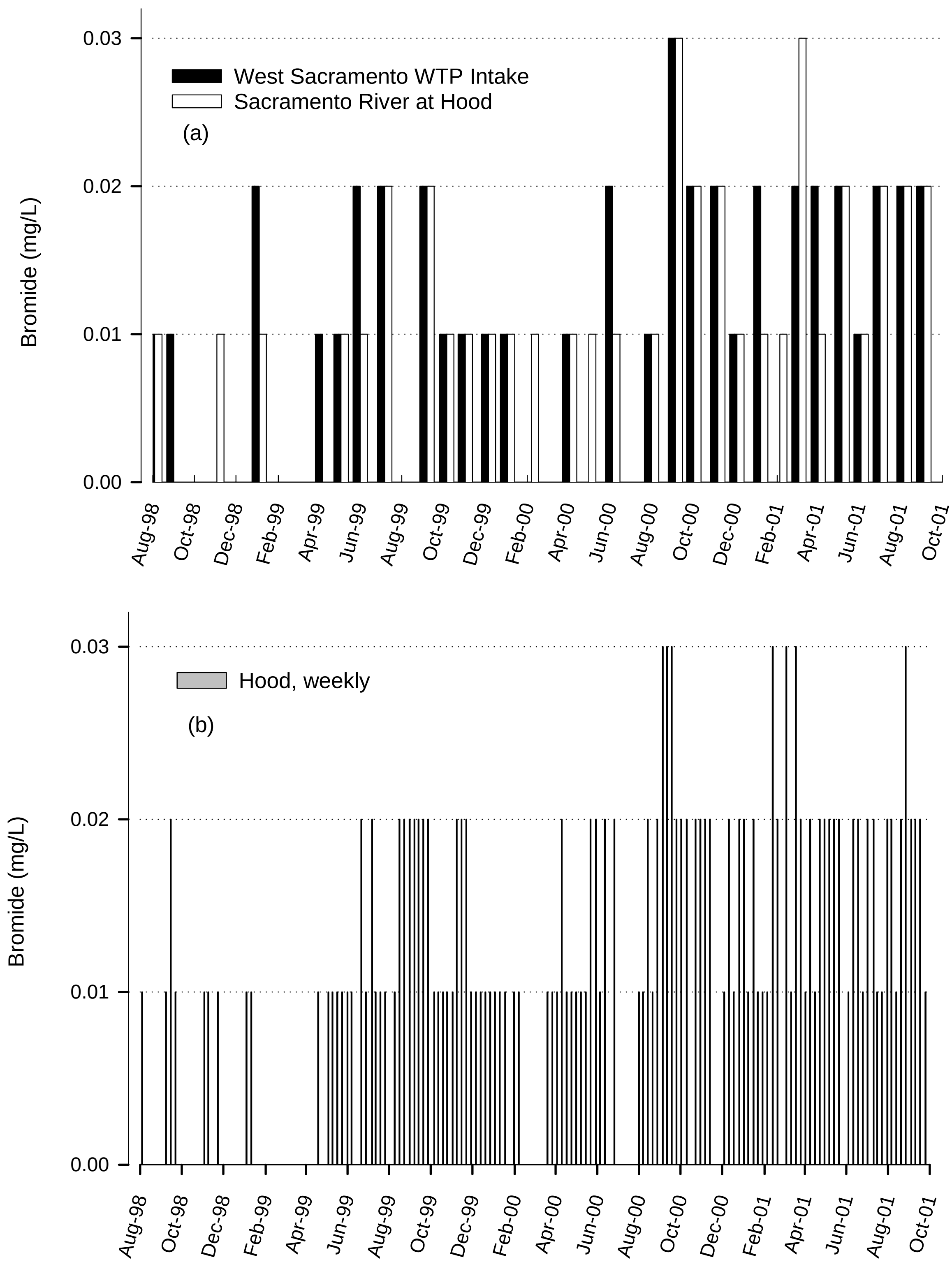


Figure 5-2 Bromide at two San Joaquin River stations

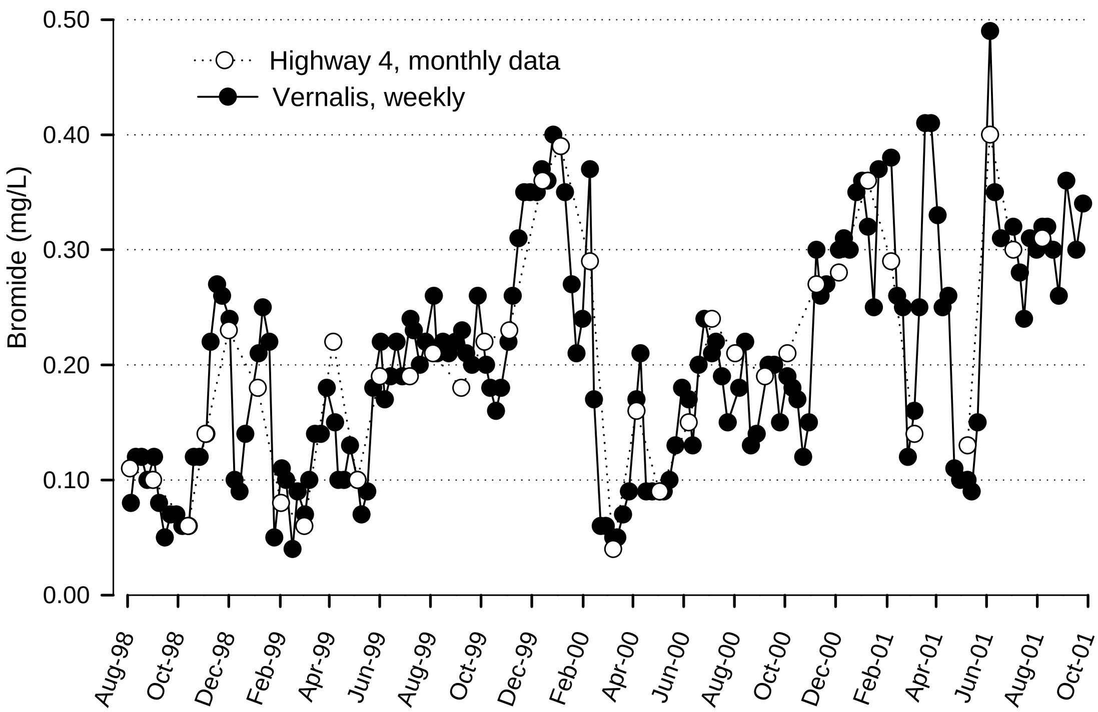


Figure 5-3 Monthly bromide concentrations at two Old River stations

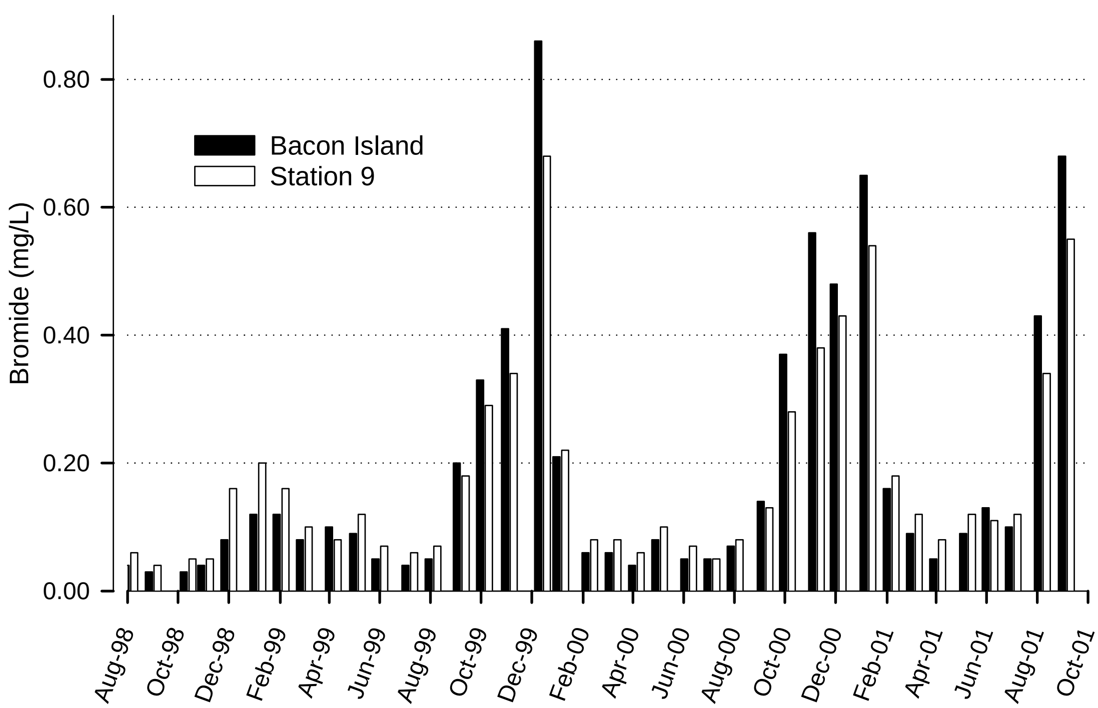


Figure 5-4 Bromide at three diversion stations

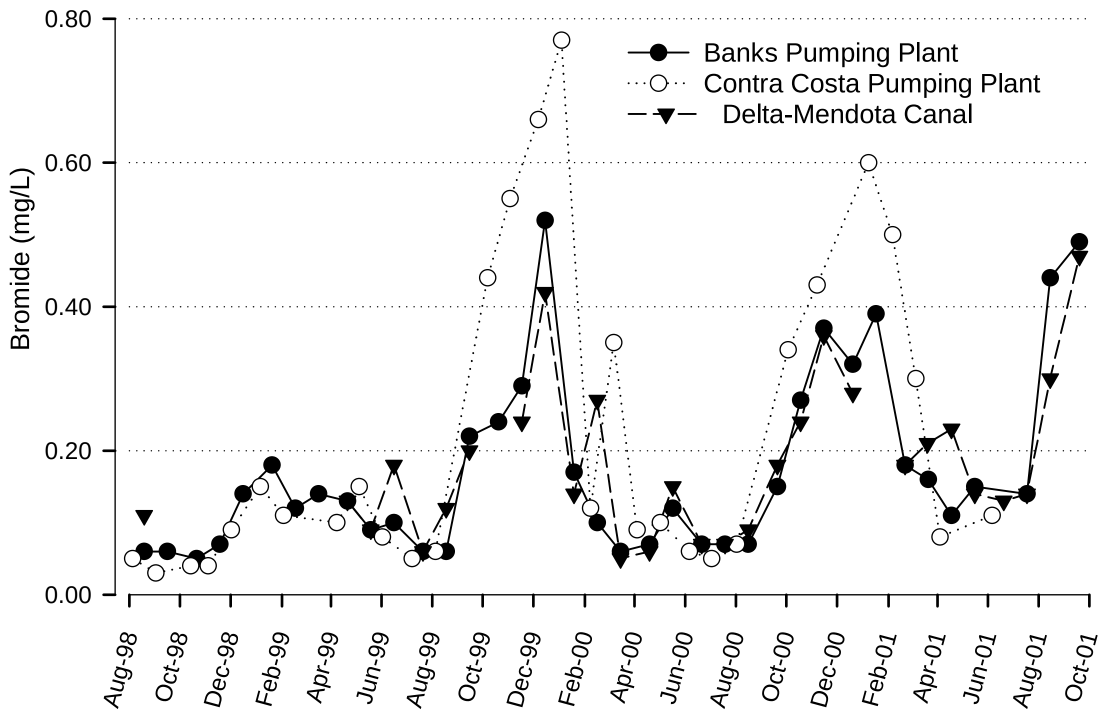


Figure 5-5 Bromide concentrations at the Mallard Island station

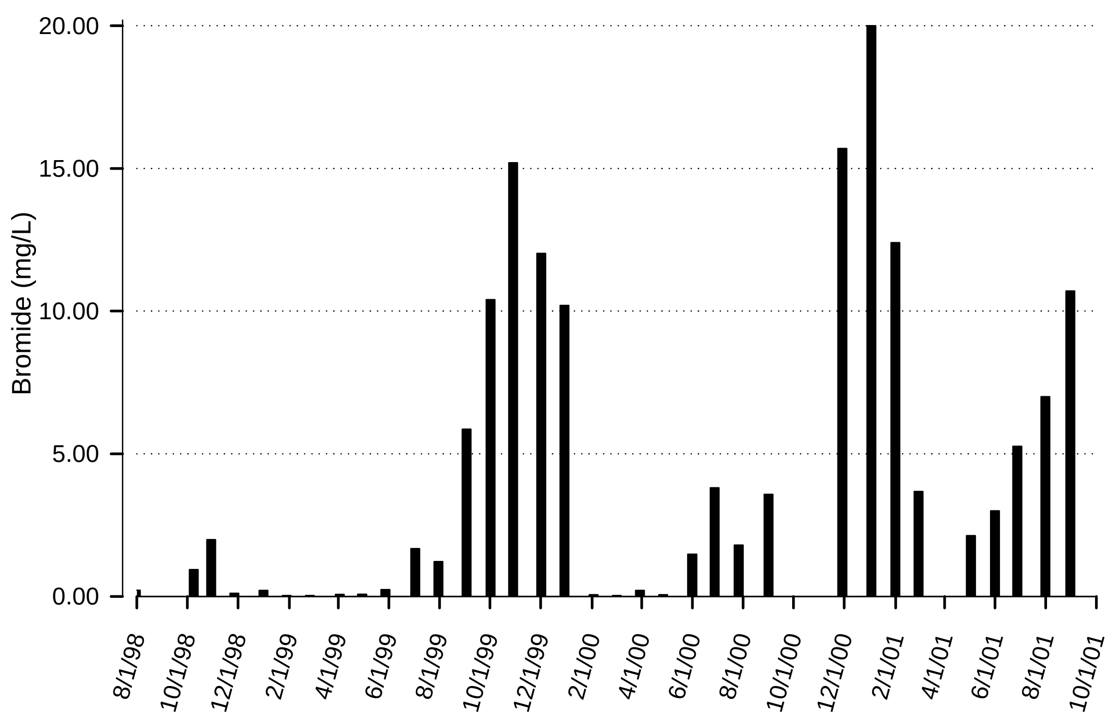
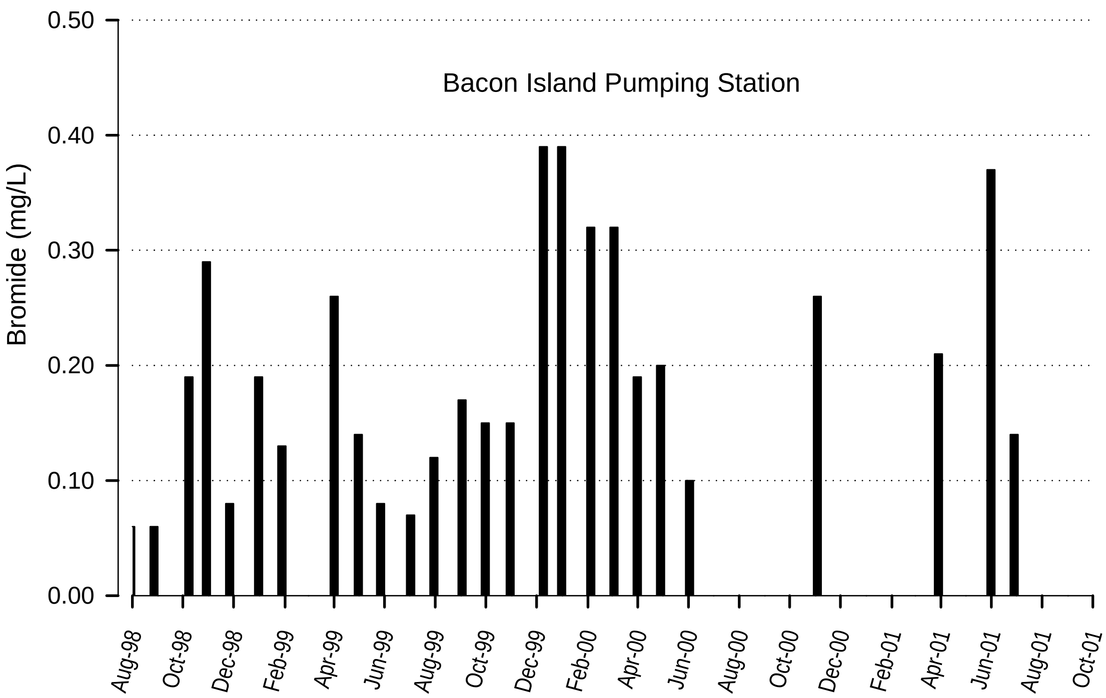


Figure 5-6 Bromide at two Delta agricultural pumping stations



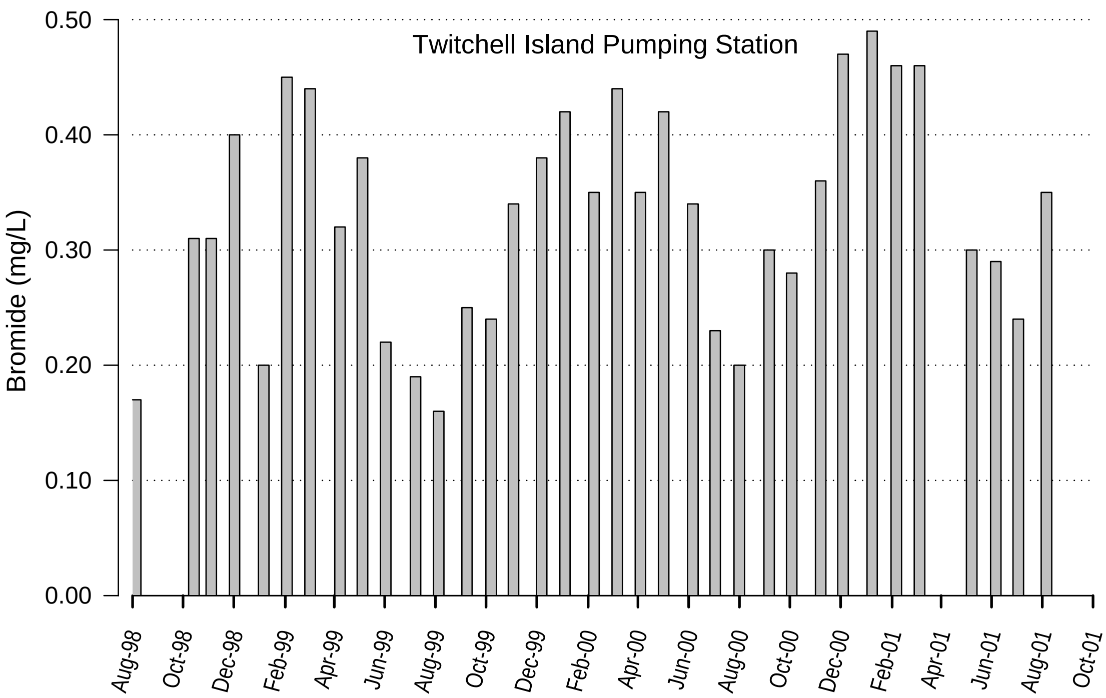


Figure 5-7 Bromide at the Natomas East Main Drainage Canal

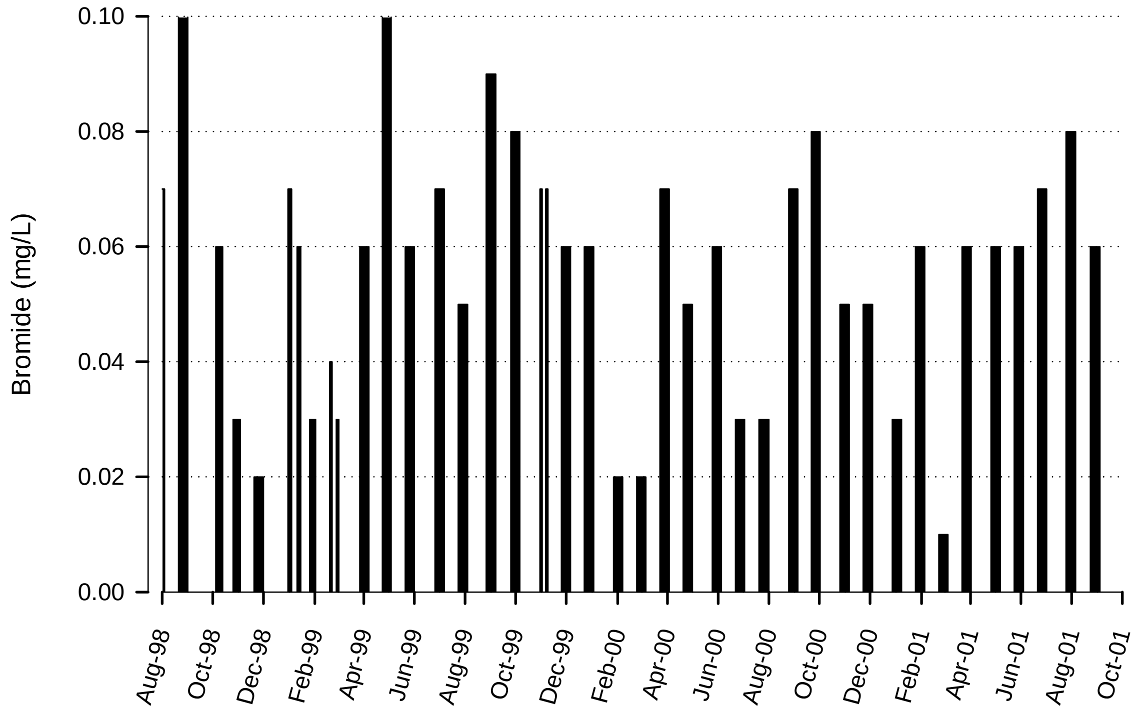
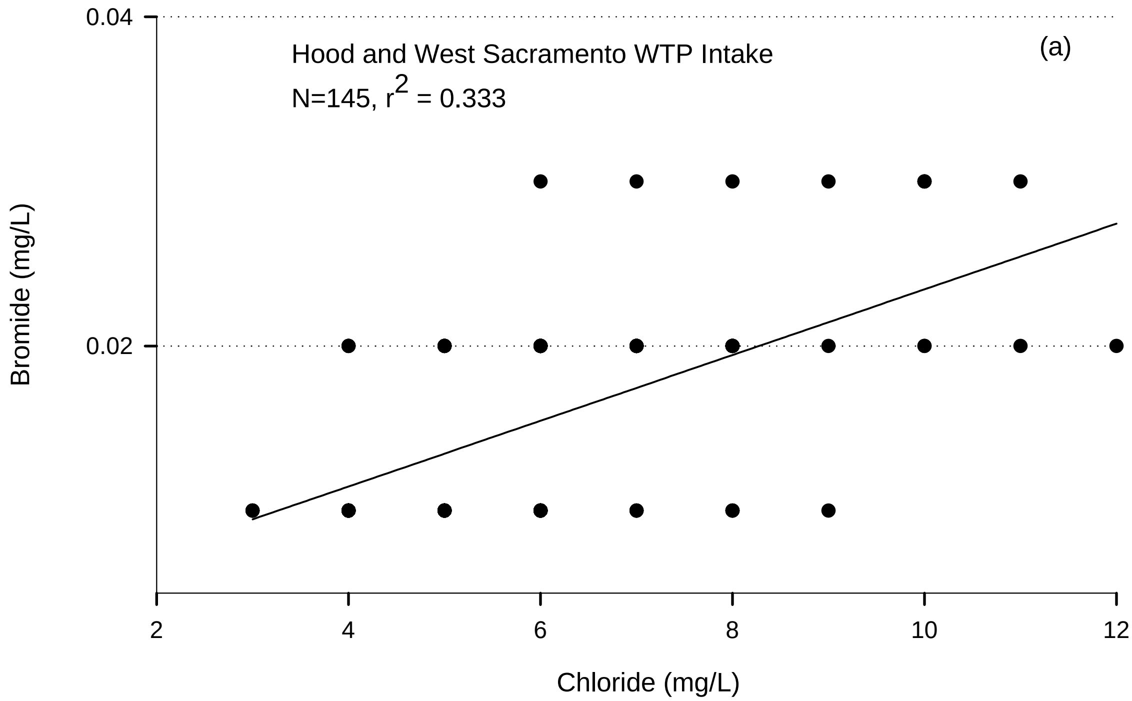


Figure 5-8 Bromide and chloride relationship at three stations



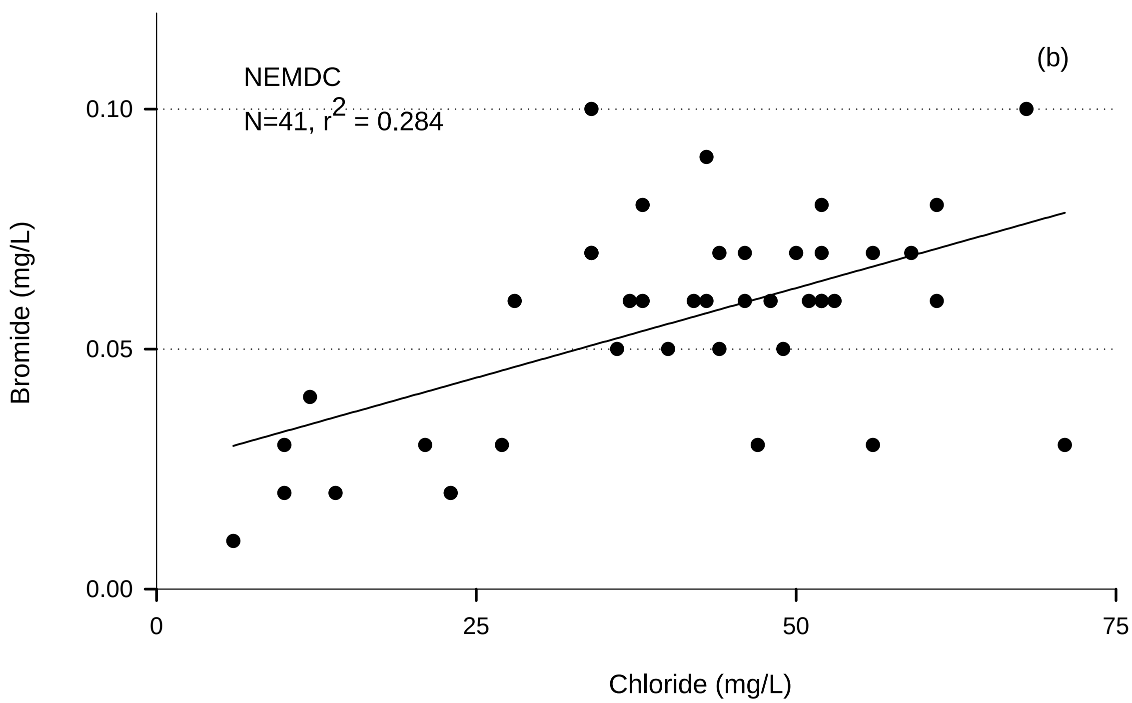


Figure 5-9 The relationship between bromide and chloride at 10 stations